SAMPLE PROBLEM NO. 23 - STRUTTED TRENCH (Medium Compact Sand)

GIVEN:

```
      |←— 6' —→|← 4' →|←—— 10' ——→|
                        ┌─────────────────┐
                        │  Q = 1,280 psf  │
                        └─────────────────┘
```

4 x 12 sheeting

6 x 6 @ 6'

6 x 8

4.25'

4.50'

1.25'
1.00'
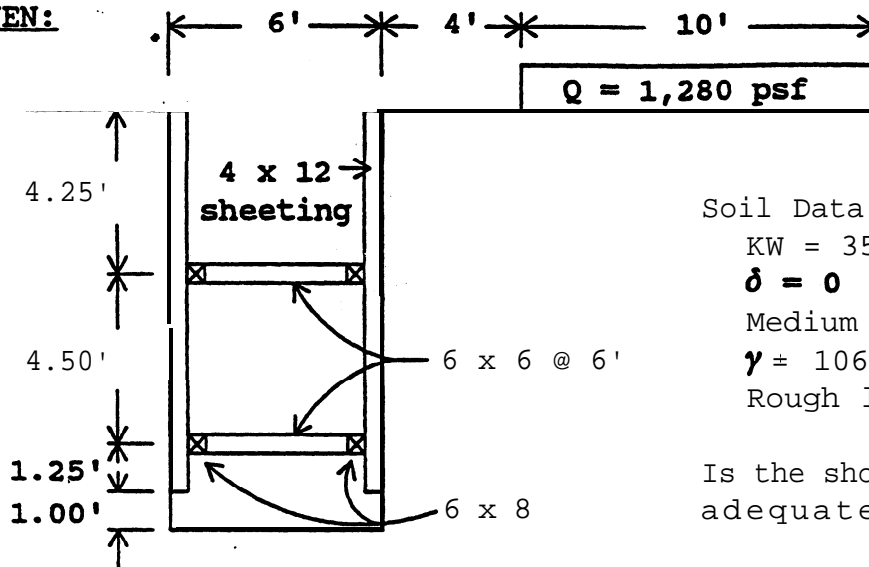
Soil Data:
KW = 35 pcf
$\delta = 0$
Medium compact sand:
$\gamma \doteq 106$ pcf
Rough lumber

Is the shoring system shown adequate?

SOLUTION:

A |←— 6.35' —→| B

11' ψ

$K_a = Kw/\gamma = 35/106$
$= 0.33$
$K_a = \tan^2(45° - \phi/2)$
$\therefore \phi = 30°$

$\psi = 45° - \phi/2 = 30°$

$AB \doteq (11)(\tan 30°)$
$= 6.35'$
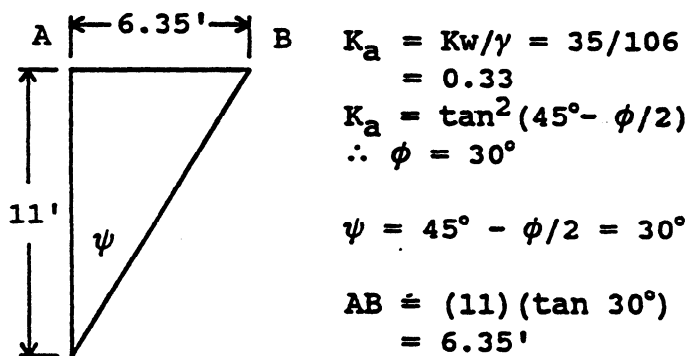
Note: Pressure diagram will be a trapezoid.

Use the tabular values listed in the section on surcharges or the Boussinesq Strip formula to find the lateral surcharge pressures. The tabular method will be used here.
Multiply the values by 1280/300 = 4.27.

Depth	Q value (0 - 14')	- Q value (0 - 4')	x 4.27	= σ
1	272.81	208.27		275.6
2	246.16	135.06		474.4
4	196.31	54.51		605.5
6	153.52	24.15'		552.4
8	118.58	12.16		454.4
10	91.21	6.81		360.4
11	80.03	5.27		319.2

Soil: Restrained System, H > 10

Surcharge:
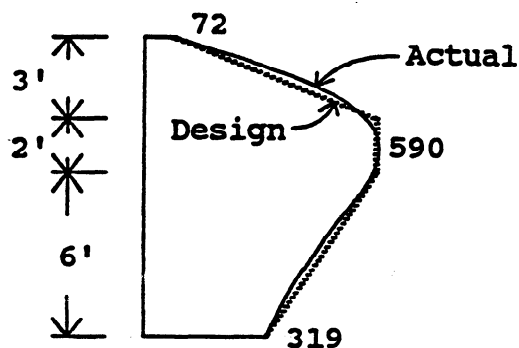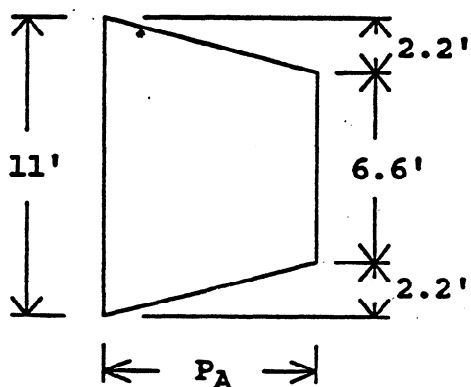
$P_A = 0.8\gamma HK_a$
$\quad = (0.8)(106)(11)(0.33)$
$\quad = 308 \text{ psf}$

Use values shown for design
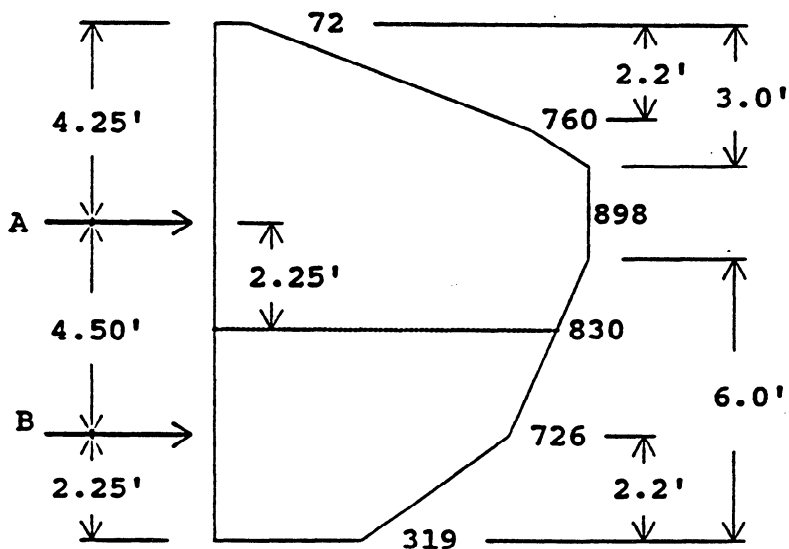
Combined Diagram

Note: For clay soils the approach would be the same: the soil pressure diagram would be modified by using the Stability Number Method.

Total force = (2.2)(72 + 760)/2 + (0.8)(760 + 898)/2 + (2.0)(898)
$\quad\quad$ + (3.8)(898 + 726)/2 + (2.2)(726 + 319)/2
$\quad\quad$ = 915 + 663 + 1,796 + 3,086 + 1,150 = 7,610 Lb/LF

A = 915 + 663 + 1,796 + (1.5)(898 + 830)/2 = 4,670 Lb/LF
B = (2.3)(830 + 726)/2 + 1,150 = 2,939 Lb/LF

APPENDIX G

CHECK SHEETING (upper cantilever)

Find M_{max}:

AREA	ARM	MOMENT
$(72)(2.2) = 158.4$	$2.2/2 + 2.05 = 3.15$	499
$(760 - 72)(2.2)/2 = 756.8$	$2.2/3 + 2.05 = 2.78$	2,104
$(760)(0.8) = 608.0$	$0.8/2 + 1.25 = 1.65$	1,003
$(898 - 760)(0.8)/2 = 55.2$	$0.8/3 + 1.25 = 1.52$	84
$(898)(1.25) = \underline{1,122.5}$	$1.25/2 = 0.63$	$\underline{707}$
2,700.9		4,397

S Req'd = M/f = $(4,397)(12)/(1,500)(1.33) = 26.4$ in^3
S Furnished = $bh^2/6 = (12)(4)^2/6 = 32.0$ in^3

Find v_{max}: $1.5V/A = (1.5)(2,701)/(4)(12) = 84$ psi < 140

CHECK SHEETING (middle section)

Assume w equals a constant 898 Lb/LF
$M = wL^2/10 = (898)(4.5)^2/10 = 1,818 < 4,397$

$V = (4.5/2 - 0.5/2 - 0.33)(898) = 1,500$ Lb
$v = 1.5V/A = (1.5)(1,500)/48 = 46.9$ psi < 140

SHEETING O.K.

CHECK WALES (upper wale controls)

$M = wL^2/10 = (4,670)(6)^2/10 = 16,812$ Ft-Lb
S Req'd = M/f = $(16,812)(12)/(1,500)(1.33) = 101.1$ in^3
S Furnished = $bh^2/6 = (6)(8)^2/6 = 64.0$ in^3

Reduce strut spacing.
Maximum L = $[(64)(1,500)(1.33)(10)/(4,670)(12)]^{1/2} = 4.77'$
Use L = 4.75' (4'- 9")

$V = (4.75/2 - 0.5/2 - 0.67)(4,670) = 6,795$ Lb
$v = 1.5V/A = (1.5)(6,795)/(6)(8) = 212.3$ psi > 140 ∴ **n.g.**

Try 8 x 8 wale

$V = (212.3)(6)/8 = 159.2 > 140$ ∴ **n.g.**

Try 8 x 8 wale with strut spacing of 4'-3"

$V = (4.25/2 - 0.5/2 - 0.67)(4,670) = 5,627$ Lb
$v = (1.5)(5,627)/64 = 131.9$ psi < 140

REVISE STRUT SPACING TO 4'- 3"

CHECK STRUT

$P/A = (4,670)(4.25)/(6)(6) = 551.3$ psi
allowable $f_c = 1300 - 20L/d$ where $L/d \leq 50$
$\qquad = 1300 - (20)(4)(12)/6 = 1,140$ psi
allowable $f_c = 480,000/[L/d]^2 = 480,000/[48/6]^2$
$\qquad = 7,500$ psi $> 1,300$ max, use 1,300 psi
$\qquad 1,140$ controls
$\qquad (1,140)(1.33) = 1,516.2 > 551.3$

CHECK COMPRESSION ON WALE

allowable $f_p = (350)(1.33) = 465.5 < 551.3 \therefore$ n.g.

Try 8 x 8 strut, $P/A = (4,670)(4.25)/(8)(8) = 310 < 465.5$

SUMMARY

Sheeting is satisfactory for the wale spacing shown.
Wales need to be 8 x 8 Rough with 4'- 3" strut spacing.
Struts need to be spaced at 4'- 3" sized 8 x 8 Rough (or 6 x 6 Rough
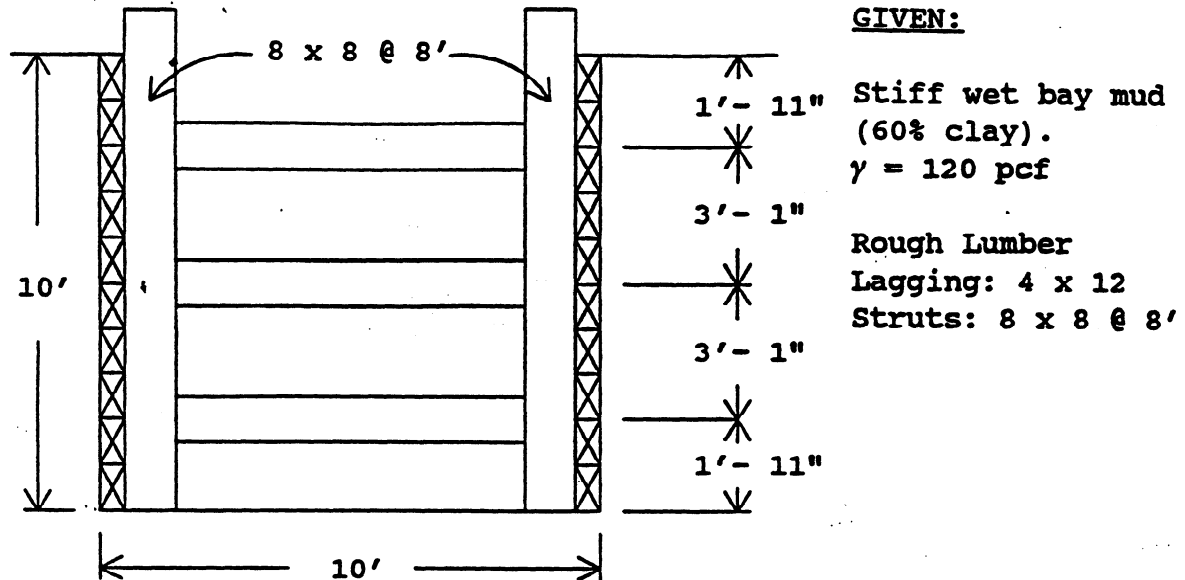with steel plates at ends).

Notes :

If the surcharge shown were to represent a building or other critical
load, the load duration factor of 1.33 would not have been used and
in this case the section modulus of the sheeting would not have been
adequate.

The top cantilever of 4'- 3" will permit settlement concurrent with
the sheeting deflection which would be detrimentalto any structure
adjacent to the excavation.

A better design would provide for three sets of wales and struts with
the wales appropriately spaced to carry similar loadings.

APPENDIX G

SAMPLE PROBLEM NO. 24 - STRUTTED TRENCH (Bay Mud)

GIVEN:

Stiff wet bay mud (60% clay).
$\gamma = 120$ pcf

**Rough Lumber
Lagging: 4 x 12
Struts: 8 x 8 @ 8'**

SOLUTION:

For soft wet conditions Kw = 120 pcf.

For restrained system and H $\leq$ 10',
may use rectangular pressure diagram.

$P_A = 0.64KwH = (0.64)(120)(10)$
$= 768$ psf.

There was no surcharge given. Use
the minimum (72 psf).

Total = 768 + 72 = 840 psf

CHECK LAGGING

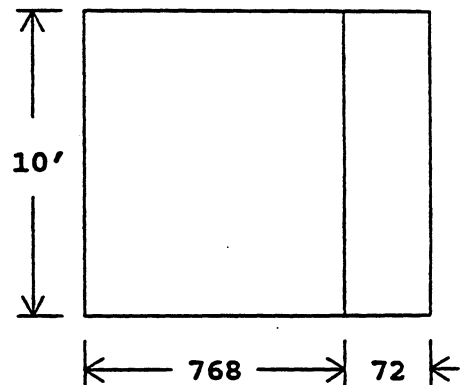Consider arching effect on lagging: Multiply all loads by 0.6.

$M = [wL^2/10]0.6 = [(840)(8)^2/10]0.6 = 3,226$ Ft-Lb

S Req'd = M/f = $(3,226)(12)/(1,500)(1.33) = 19.4$ in^3

S furnished = $bh^2/6 = (12)(4)^2/6 = 32.0$ in^3 > 19.4

$Y = [(8/2 - 0.33 - 0.33)(840)](0.6) = 1,683$ Lb

$v = 1.5V/A = (1.5)(1,683)/(4)(12) = 52.6$ psi < 140

G-S

CHECK 8 x 8 UPRIGHTS.

Middle Section
$M = (8)(840)(3.08)^2/10 = 6,375$ Ft-Lb
$V = (3.08/2 - 0.33 - 0.67)(840)(8) = 3,629$ Lb

Cantilever section
$M = (8)(840)(1.92)^2/2 = 12,386$ Ft-Lb
$V = (1.92 - 0.33 - 0.67)(840)(8) = 6,182$ Lb

S Req'd $= (12,386)(12) /(1,500)(1.33) = 74.5$ in^3
S Furnished $= (8)(8)^2/6 = 85.3$ in$^3 > 74.5$

$v = (1.5)(6,182)/64 = 144.9 > 140 \therefore$ n.g.

Increase strut spacing from 3'- 1" to 3' 3"

$V = (1.75 - 0.33 - 0.67)(840)(8) = 5,040$ Lb
$v = (1.5)(5,040)/64 = 118.1 < 140$

CHECK STRUTS

$P/A = (840)(8)(1.75 + 3.25/2)/(8)(8) = 354.4$ psi

Allowable $f_c = 480,000/(L/d)^2 = 480,000/(96/8)^2$
            $= 3,333$ psi $> 1,600$ max, use 1,600 psi
            1,600 controls > 354.4 psi o.k.

CHECK COMPRESSION ON UPRIGHT
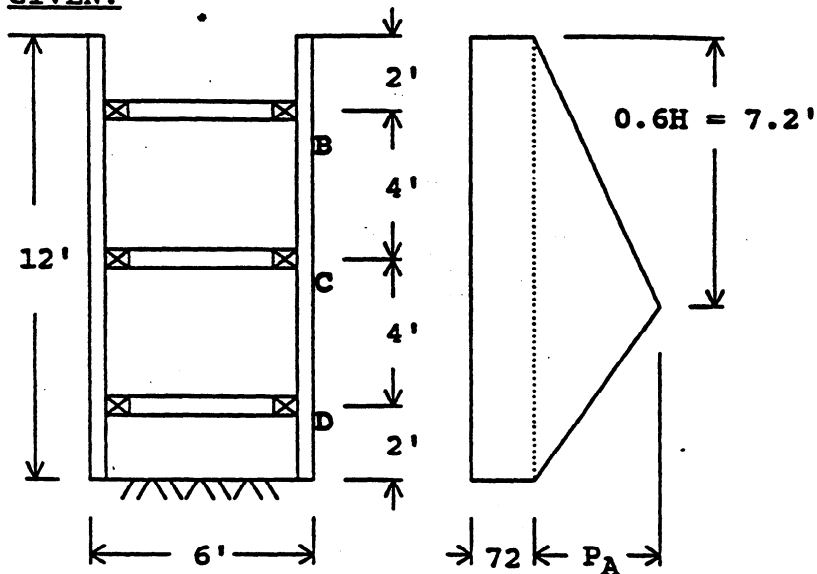
Allowable $f_p = (350)(1.33) = 465.5 > 354.4$

System will be satisfactory if top and bottom cantilever dimensions are changed from 1' -11" to 1' - 9", and the vertical spacing between strut is accordingly revised from 3'- 1" to 3'- 3".

SAMPLE PROBLEM NO. 25 - STRUTTED TRENCH (Medium Clay)

GIVEN:

Method by
Tschebotarioff

From Soils Report

γ = 115 pcf
q_u = 2,000 psf

Materials

Sheeting: 2 x 12
Wales: 6 x 8
Struts: 6 x 8 @ 6'
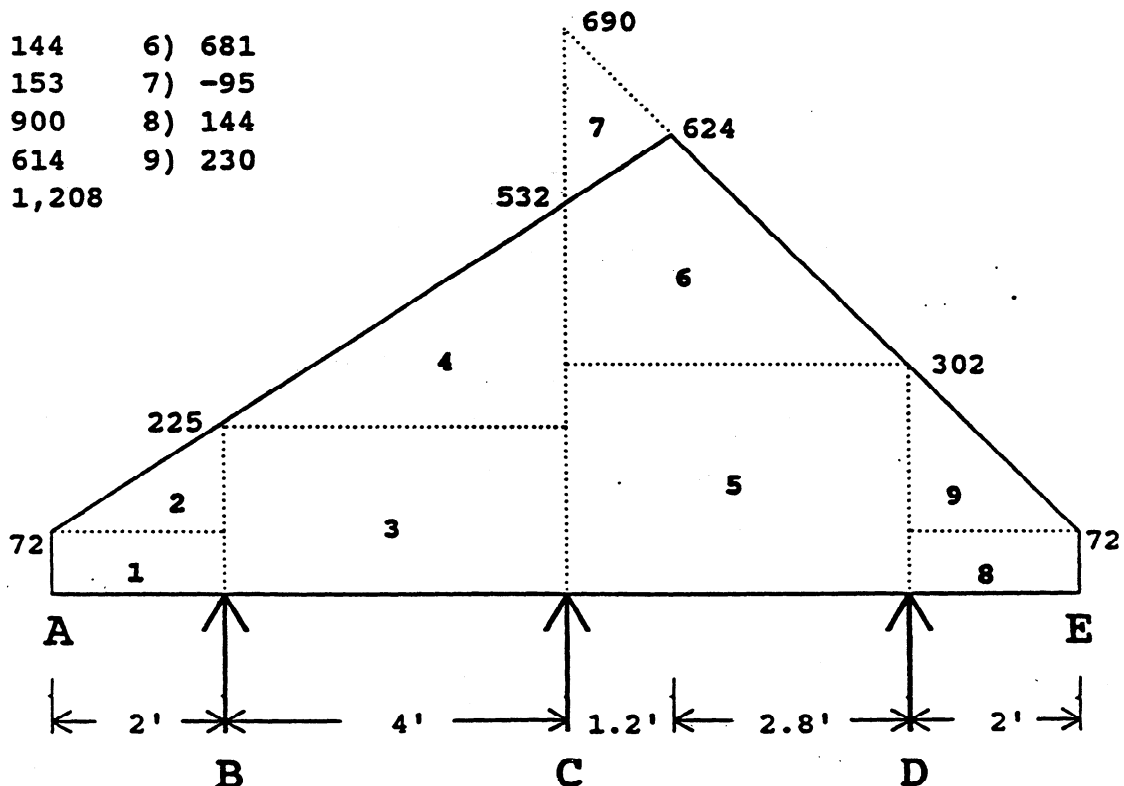All rough lumber

P_A = **0.4γH**
   = (0.4)(115)(12)
   = 552 psf

No surcharge given
Use minimum 72 psf

SOLUTION:

AREAS (Lb/LF)

1) 144   6) 681
2) 153   7) -95
3) 900   8) 144
4) 614   9) 230
5) 1,208

Find Maximum Moment (use moment distribution):

Fixed end moments (Ft-Lb/LF)

1) $(72)(2)[2/2]$ $= 144$
2) $\{(153)(2)/2\}[2/3] = 102$

$B\,A = 2\,4\,6$

3) $(225)(4)^2/12$ $= 300$ $= 300$
4) $(327)(4)^2/30$ $= \underline{174}$

$(327)(4)^2/20$ $=2\,6\,2$

$BC = 474$ $CB = 562$

5) $(302)(4)^2/12$ $= 403$ $= 403$
6) $(388)(4)^2/20$ $= 310$

$(388)(4)^2/30$ $= 207$

7) $[(-158)(4)^2(0.3)^2/60][10 - (10)(0.3) + (3)(0.3)^2] = \underline{-28}$

$[(-158)(4)^2(0.3)^2/60][5 - (3)(0.3)]$ $= \underline{-16}$

$CD = 685$

$DC = 594$

8) $(72)(2)[2/2]$ $= 144$
9) $\{(230)(2)\}[2/3] = 153$

$DE = 297$

	B		C		D	
	0 | 1.0		0.5 | 0.5		1.0 | 0	
	−246	**+474**	**−562**	**+685**	**−594**	**+297**
		−228	**−61.5**	**−61.5**	**+297**	
		−30.7	**−114**	**+148.5**	**−30.7**	
		+30.7	**−17.3**	**−17.3**	**+30.7**	
	246	**+246**	**−755**	**+755**	**−297**	**+297**
MV		**−127.2**	**+127.2**	**+114.5**	**−114.5**	
	+144	**+450**	**+450**	**+604**	**+604**	**+144**
	+153	**+204.7**	**+409.3**	**+517.3**	**+258.7**	**+230**
				−66.4	**−28.4**	
	825		**2,156**		**1,094**	

CHECK SHEETING:

By inspection, the maximum moment will either be at C or between c and D.

$M_C = -755$ Ft-Lb/LF
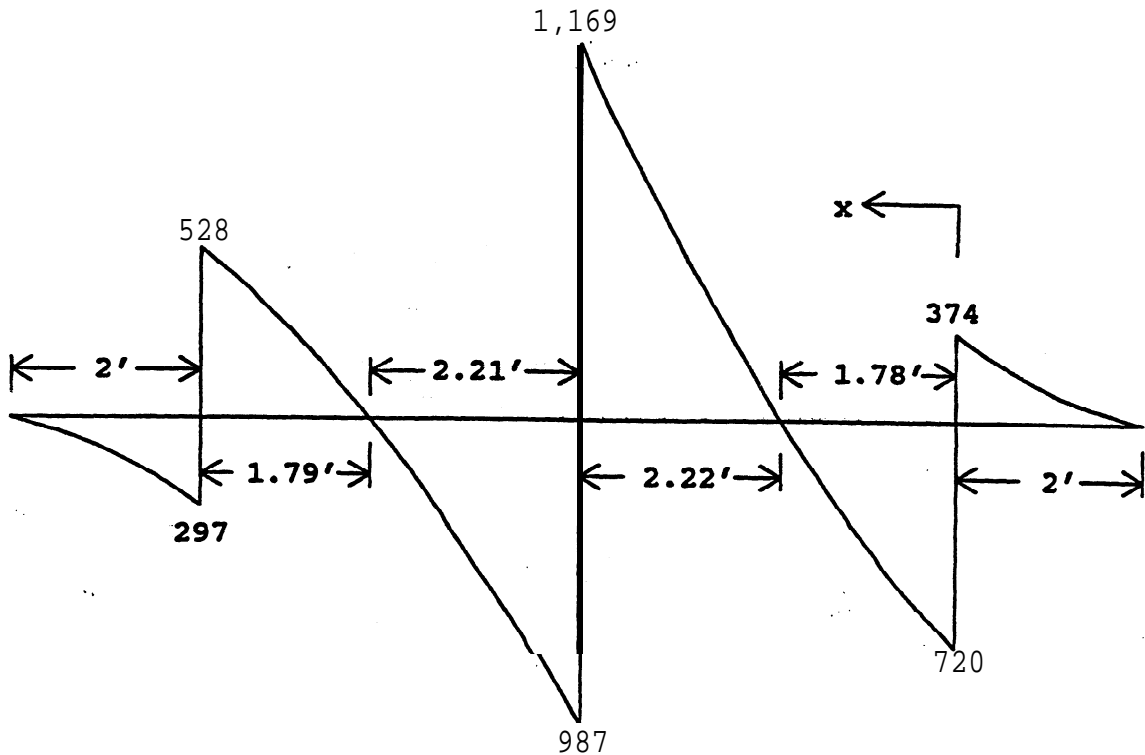
Find point of zero shear between C and D.

720 - 302X - (624 - 302)(x/2.8)(x)/2 = 0

$57.5x^2 + 302X_1 - 720 = 0$

X- 1.78'

M = -(302) (1.78)[1.78/2] - {(322)(1.78/2.8)(1.78)/2}[1.78/3]
    + 1,094[1.78] - 144[1.78 + 2/2] - 230[1.78 + 2/3]
  = 398 Ft-Lb/LF

M_C controls (M = -755 Ft-Lb)

S req'd = M/f = (755)(12)/(1,500)(1.33) = 4.54 in^3

S furnished = $(12)(2)^2/6$ = 8.0 in^3

v= 1.5V/A = (1.5)(1,169)/(2)(12) = 73.1 < 140 psi

CHECK WALES (center controls):

M = $(2,156)(6)^2/10$ = 7,762 Ft-Lb

S req'd = (7,762)(12)/(1,500)(1.33) = 46.7 in^3

S furnished = (6)(8)^2/6 = 64 in^3
V = (6/2 - 0.33 - 0.33)(2,156) = 5,045 Lb

v = (1.5)(5,045)/(6)(8) = 157.7 psi > 140

Use 8 x 8's v = (157.7)(48/64) = 118 < 140

CHECK STRUTS (center controls):

P/A = (2,156)(6)/(6)(8) = 270 psi

allowable f_c = 480,000/[L/d]^2 = 480,000/[(4.33)(12)/6]^2
$\qquad$ = 6,400 psi > 1,600 max, use 1,600 psi
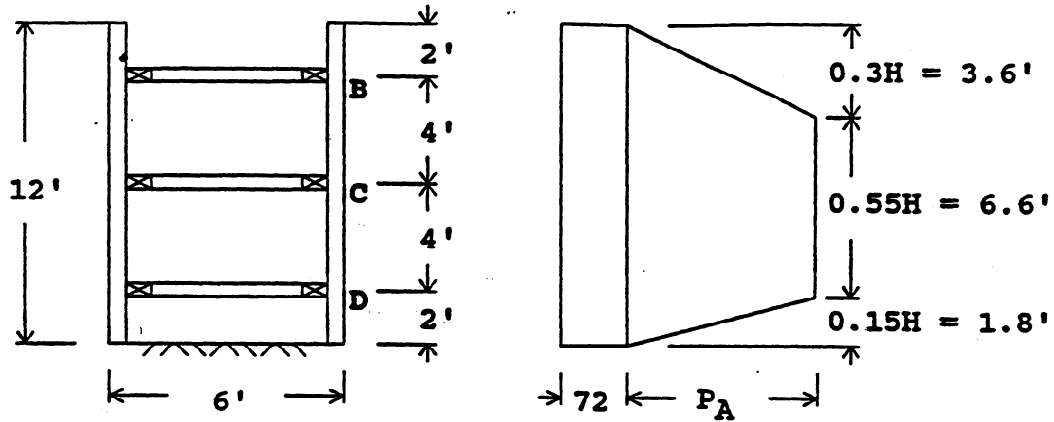$\qquad\quad$ 1,600 controls > 270 psi o.k.

SUMMARY

Sheeting is satisfactory for the wale spacing shown.
Wales need to be 8 x 8.
Struts okay as shown

A better approach would be to use the more conventional trapezoidal
earth pressure diagram as it is easier to work with. This is
demonstrated on the following page.

SAMPLE PROBLEM NO. 25 - STRUTTED TRENCH: ALTERNATE ANALYSIS

$P_A = \gamma H - 2q_u = (115)(12) - (2)(2,000) \leq 0$

Use Stability Number Method:
$N_O = \gamma H / c$ $(115)(12)/600 = 2.3$
$P_A = (C/150)(7N_0^2 + 10N_o) = 240$ psf
P_a = Minimum Surcharge = 240 + 72 = 312

Top strut = $(240)\{(4 + 0.4)/2\}(6) + (72)(4)(6) = 4,896$ Lb
Center strut load = $(312)(4)(6) = 7,488$ Lb
Bottom strut = $(240)\{(4 + 2.2)/2\}(6) + (72)(4)(6) = 6,192$ Lb
(All of which are less than the Tschebotarioff analysis)

Determine maximum moment of sheeting.

$M_C = -(240)(4.2) [4.2/2] - \{(240)(1.8)/2\}[4.2 + 1.8/3]$
$\quad\quad -(72)(6)[6/2] + (6,192/6)[4] = -322$

M_{CD} moment at midpoint between C and D
$\quad = -(240)(2.2)[2.2/2] - \{(240)(1.8)/2\}[2.2 + 1.8/3]$
$\quad\quad - (72)(4)[4/2] + (6,192/6)[2] = 302$

$M_{DE} = -(240)(0.2) (0.1) - \{(240)(1.8)/2\}[0.2 + 1.8/3]$
$\quad\quad - (72)(2)[2/2] = -322$

Use M = -322 Ft-Lb/LF < -755 (from previous analysis). $\therefore$ o.k.
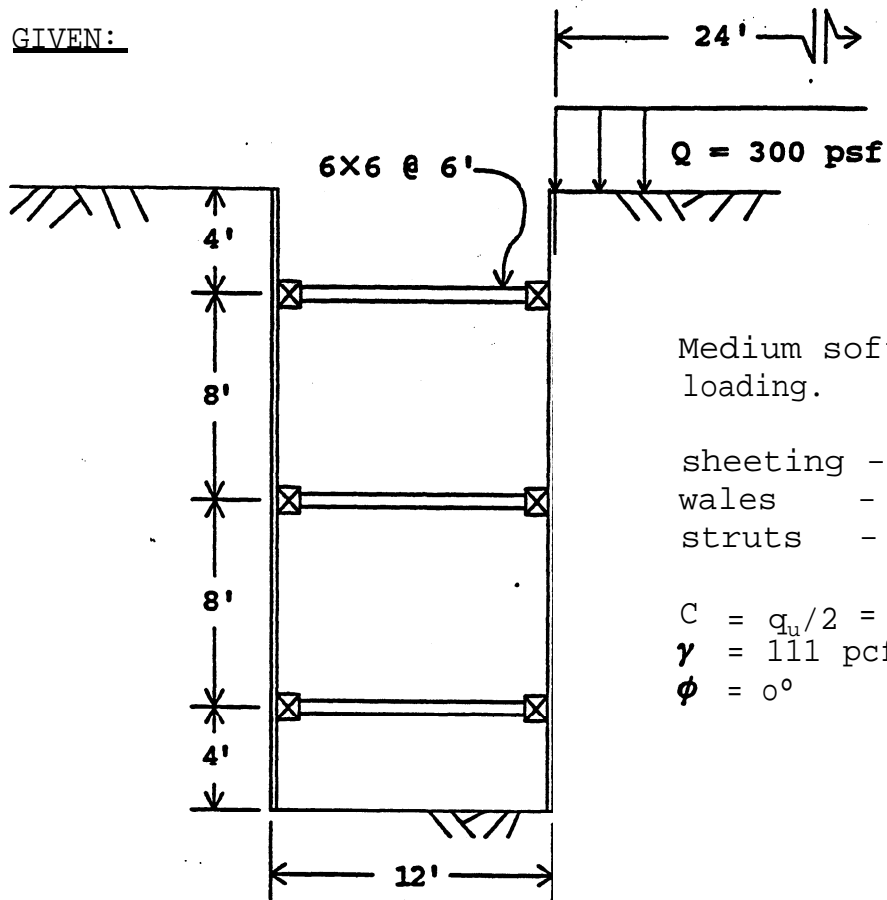
By inspection, all other members check.

Center of soil pressure is smaller by this conventional method, but the top and bottom struts are more appropriately loaded.

SAMPLE PROBLEM NO. 26 - STRUTTED TRENCH: (Medium Soft Clay)
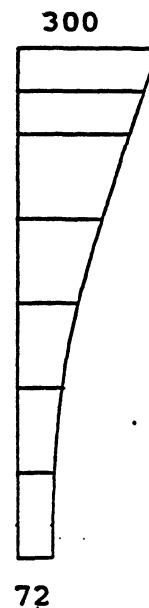
GIVEN:

Medium soft clay, short term loading.

sheeting - 4 X 12 (Rough)
wales   - 12 X 12 (Rough)
struts   - 6 X 6 (Rough)

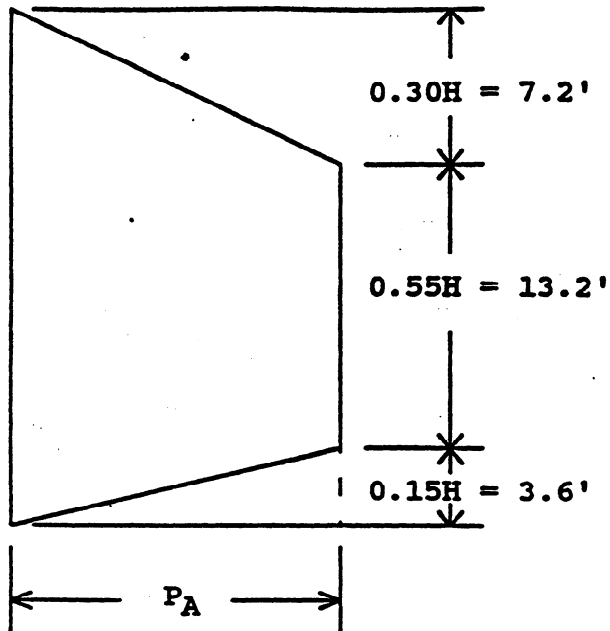$C = q_u/2 = 400$ psf
$\gamma = 111$ pcf
$\phi = 0°$

SOLUTION:

Boussinesq strip surcharge values:

Depth	Lateral Pressure
2	268
4	237
8	181
12	135
16	100
20	73
24	72 (minimum)

Soil Pressure Diagram

**Soil Pressure Diagram
(Terzaghi & Peck)**

$$P_A = \gamma H - 4C$$
$$= 111(24) - 4(400)$$
$$= 1064 \text{ PSF}$$

OR

$$P_A = 0.375\gamma H$$
$$= 0.375(111)(24)$$
$$= 999 \text{ PSF}$$

use $P_A = 1064$ PSF

Kw may be computed once the shape of the pressure diagram is established.

Total Area = Total Pressure

$$(0.3H)P_A/2 = 0.150P_AH$$
$$(0.55H)P_A = 0.550P_AH$$
$$(0.15H)P_A/2 = \underline{0.075P_AH}$$
$$\text{Total Force} = 0.775P_AH$$

Normalizing $= 0.8/(0.775)(0.8) = 0.8258$
$P_A = 0.8258KwH = 1064$
$Kw = 53.7$ PCF

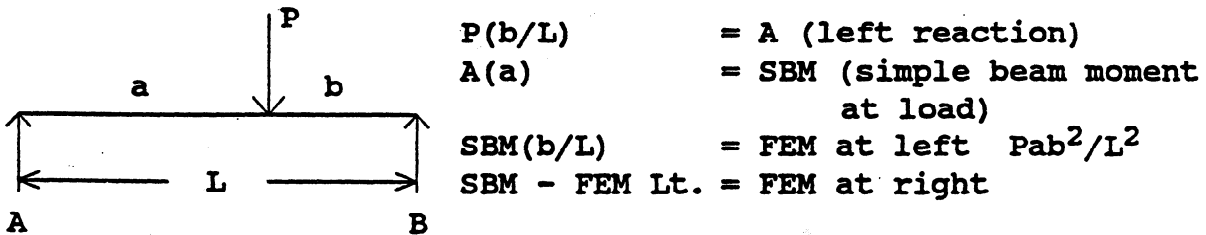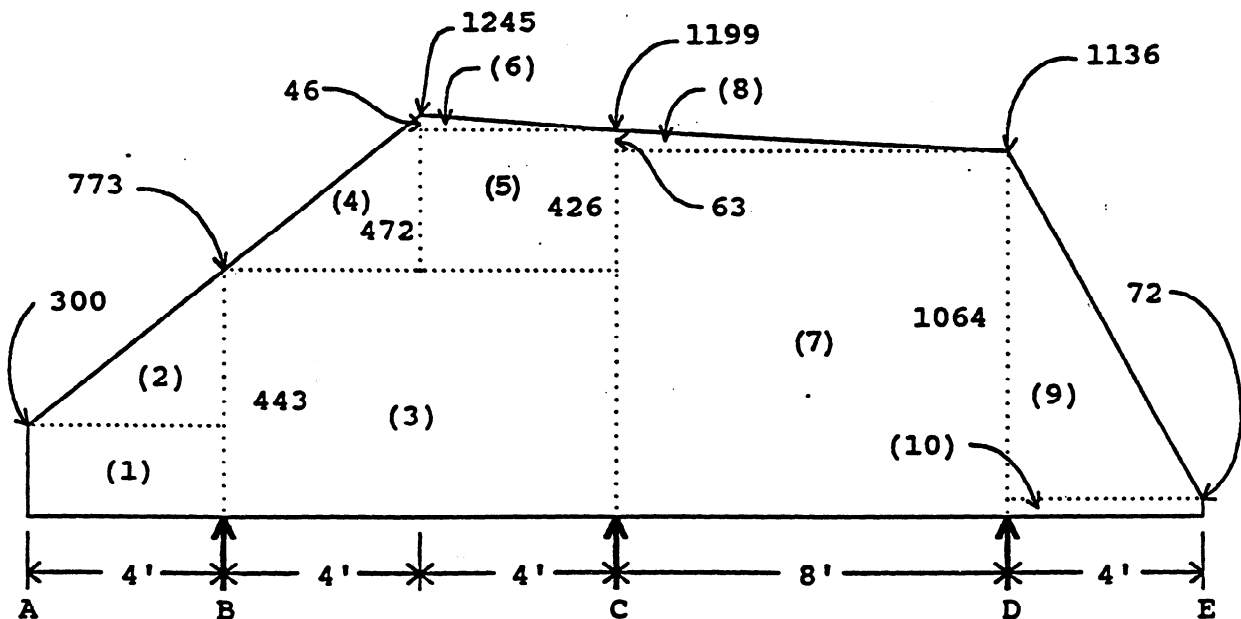Adding soil and surcharge pressures:
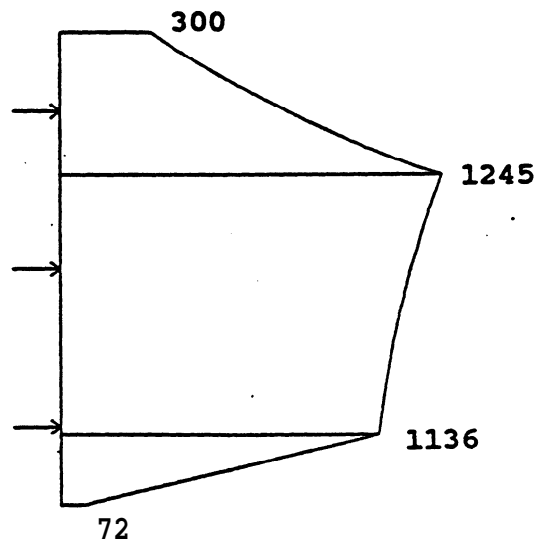
With the loading diagram complete, the strut reactions can be determined using moment shears calculated from the fixed end moments of each span.

First determine the fixed endmoments and use moment distribution to balance the loads.

For simple moment distribution, small triangles may be converted to concentrated loads placed at the triangle centroids.

P(b/L)	= A (left reaction)
A(a)	= SBM (simple beam moment at load)
SBM(b/L)	= FEM at left Pab^2/L^2
SBM - FEM Lt.	= FEM at right

Compute the simple beam fixed end moments.

(1) 300(4) = 1200 $300(4)^2/12$ = 2400
(2) 473(4)/2 = 946   946(4)/3   = 1261
                               FEM BA = 3661

(3) 773 (8) = 6184 $733(8)^2/12$ = 4123   4123
(4) 472(4)/2 = 944   944(4 + (4/3))/8   = 629
                       629 (2/3) (4)   = 1678 SBM
                       1678(4 + (4/3))/8   = 1119   559

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(5)  426(4)   = 1704    1704(4/2)/8      =  426
                        426(4 + (4/2))   =  556
                        2556(4)/(2)(8) = 639              1917
(6)   46(d)   =   92    92(2/3)(4)/8     =   31
                        31(4 + (4/3)     =  165 SBM
                        165(2/3) (4)/8   =   55              110
                                 FEM  BC = 5936   FEM CB = 6709


(7)  1136(8)  = 9088    1136(8)²/12      = 6059              6059
(8)  63(8)/2  =  252    252(2/3) (8)/8   =  168
                        168(8)/3         =  448 SBM
                        448(2/3)(8)/8  =  299               149
                                 FEM CD  = 6358   FEM DC = 6208


(9) 1064(4)/2 = 2128    2128(4/3)        = 2837
(10)  72(4)  =  228     72(4)²/2         =  576
                             FEM DE = 3413
Sum of Loads = 22,826 LB/LF
```

Moment Distribution:

0	1		0.5	0.5		1	0
-3661	+5936		-6706	+6358		-6208	+3413
	-2275		+ 176	+ 176		+2795	
	+ 88		-1138	+1398		+ 88	
	- 88		- 130	- 130		- 88	
	- 65		- 44	- 44		- 65	
	+ 65		+ 44	+ 44		+ 65	
-3661	+3661		-7802	+7802		-3413	+3413

Calculate the strut reactions. This is done by summing the
moment shears and the simple beam shears. Moment shears are
the difference between the simple beam FEMs divided by the
span length. This distributes the load to account for the
actual condition of a continuous beam.

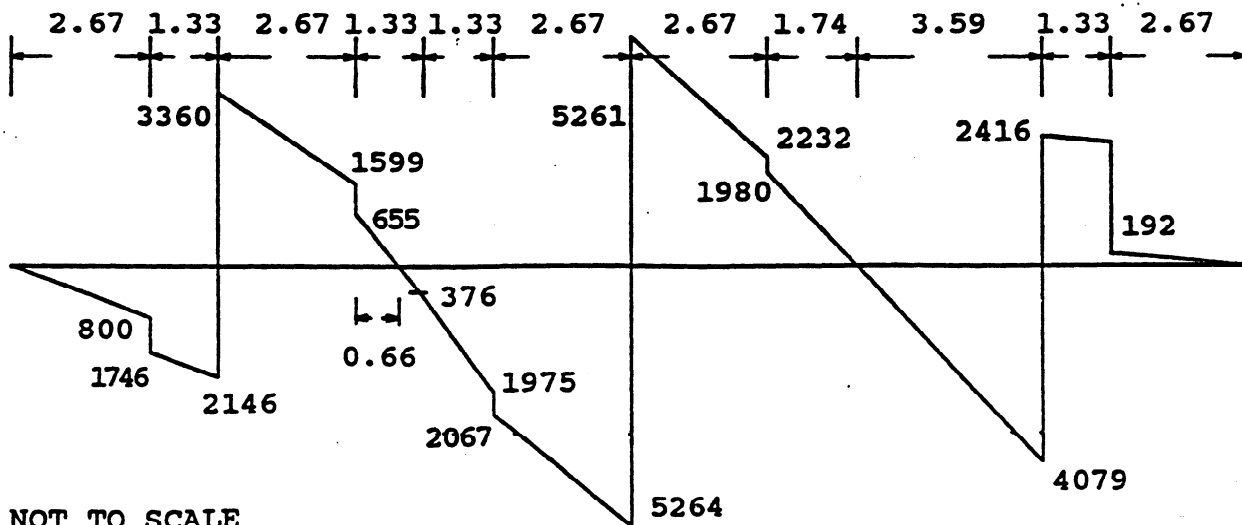| Moment Shears		- 518:	+ 518	+ 549	- 549	
Simple		3092	3092	4544	4544	
Beam	1200	629	315	168	84	2128
Shears	946	426	1278			228
		31	61			
Reactions	5806		10525		6495	

Sum of Reactions = 22,826 = Sum of Loads.   CHECK

Determine the shear diagram.
The portion contributed by
the triangular load can be
approximated by breaking it
into two straight line slopes
at a third point.

actual shear diagram

approximate shear diagram

loading diagram
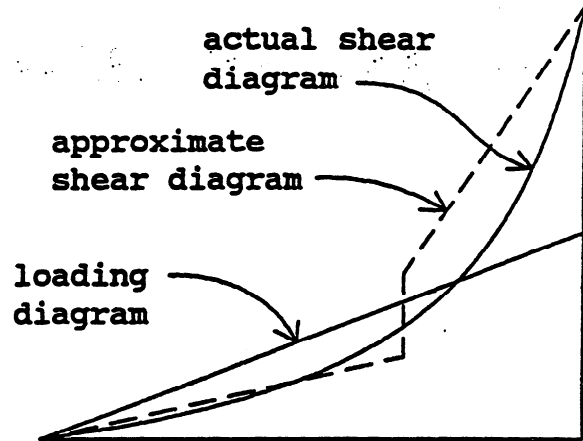
Approximate Shears

300(2/3) (4)	=–	800
(2)	=–	946
	=–	1746
300(4)/3	= –	400
	= –	2146
B	= +	5806
	= +	3360
773(2/3)(4)	=–	2061
	= +	1599
(4)	= –	944
	=+	655
773 (1/3) (4)	= –	1031
	=–	376
1199(1/3)(4)	= –	1599
	=–	1975
(6)	= –	92
	= –	2067

	=–	2067
1199(2/3)(4)	= –	3197
	=–	5264
C	= +	10525
	= +	5261
1136(1/3)(4)	= –	3029
	= +	2232
(8)	=–	252
	= +	1980
1136(2/3) (8)	= –	6059
	= –	4079
D	=+	6495
	= +	2416
(9)	=–	2128
	=+	288
(10)	=–	288
CHECK	=	0

2.67 1.33 2.67 1.33 1.33 2.67   2.67 1.74   3.59   1.33 2.67

3360

1599

655

376

800

1746

0.66

2146

2067

1975

5261

1980

2232

5264

2416

192

4079

NOT TO SCALE

G–16

From the values in the shear diagram calculate the values for
l - the approximate moment diagram.

Approximate Moment Calculations:

800(2.67)/2	=	-1068 Ft-Lb/LF
1746(1.33)/2	=	-1116
2146(1.33)/2	=	<u>-1427</u>
	=	-3656
3660(2.67)/2	=	+4886
1599(2.67)/2	=	<u>+2135</u>
	=	+3365
655(0.66)/2	=	<u>+ 216</u>
	=	+3581
376(0.67)/2	=	<u>- 126</u>
	=	+3455
376(1.33)/2	=	- 250
1975(1.33)/2	=	<u>-1313</u>
	=	+1892
2067(2.67)/2	=	-2759
5264(2.67)/2	=	<u>-7027</u>
	=	-7894 MAXIMUM
5261(2.67)/2	=	+7023
2232(2.67)/2	=	<u>+2980</u>
	=	+2109
1980(1.74)/2	=	<u>+1723</u>
	=	+3832
4079(3.59)/2	=	-7322
	=	-3490
2416(1.33)/2	=	+1607
2320(1.33)/2	=	<u>+1534</u>
	=	- 340
192(2.67)/2	=	+ 256
	=	- 84 Close enough - CHECK

Check the shoring system members.

Sheeting 4 X 12 (Rough)

$S = bh^2/6 = 12(4)^2/6 = 32$ in^3
S required $= M/F = 7894(12)/(1500)(1.33) = 47$ in^3

Try 6 X 12 (Rough)

$S = 12(6)^2/6 = 72$ in^3 OK

Note that the 0.6 lagging arching factor is not used with sheeting or with soft clay.

Wales 12 X 12 (Rough)

$S = 12(12)^2/6 = 288$ in^3

Center controls, use $M = wl^2/10$

S required $= 10525(6)^2(12)/(10)(1.33)(1500) = 228$ in^3

Length for shear $= 6/2 - 0.5 - 1 = 1.5$ Ft.

$v = 3(1.5)(10525)/2(12)(12) = 164$ psi $> 110(1.33) = 146$ psi

Try a 12 X 16 (Rough)

$v = 128$ psi < 146 psi OK

Strut 6 X 6 (Rough)

Center controls.

Strut length $= 12 - 2(1.33 + 0.33) = 8.68$ Ft.

$P/A = 10525(6)/(6)(6) = 1754$ psi

Allowable:

$480000/(8.68(12)/6)2 = 1592$ psi < 1600 psi Maximum

Try a 8 X 8 (Rough)

$P/A = 10525(6)/(8)(8) = 987$ psi < 1592 psi o.k.

Bearing value on wale $= 987 > 350$ psi Allowable.
Provide steel plates at ends of struts.

APPENDIX G

SUMMARY

All materials are too small for 6'-O" spacing of struts.

    May use: Sheeting = 6 X 12 (Rough)
             Wales = 12 X 26 (Rough)
             Struts = 8 X 8 (Rough)
             Steel bearing plates will be needed at
                ends of the struts to provide adequate
                bearing area to prevent overstess in
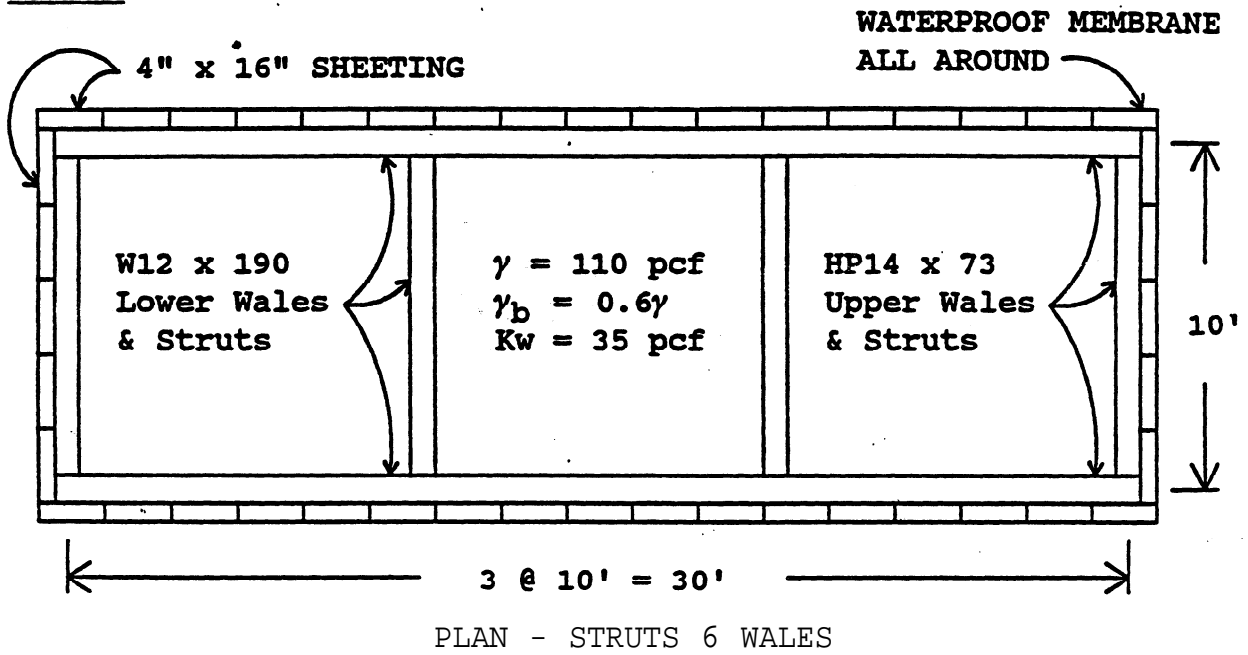   compression perpendicular to the
                grain of the wales.

Wale and strut requirements could be reduced by decreasing the
spacing of the struts.

APPROXIMATE METHOD

In lieu of doing moment distribution, assume average load on
center strut = 1200 PSF X 8 foot strut spacing X l.1 for moment
and shear continuity = 1200(8)(1.1) = 10560 (versus 10,525).
Check member adequacies.

SAMPLE PROBLEM No. 27 - COFFERDAM

GIVEN:

4" x 16" SHEETING

WATERPROOF MEMBRANE ALL AROUND

W12 x 190
Lower Wales
& Struts

$\gamma = 110$ pcf
$\gamma_b = 0.6\gamma$
$Kw = 35$ pcf

HP14 x 73
Upper Wales
& Struts

10'

3 @ 10' = 30'

PLAN - STRUTS 6 WALES

8'

15.5'

5'

(1)

tremie seal

(2)

footing

tremie seal

4'

2.5'

(3)
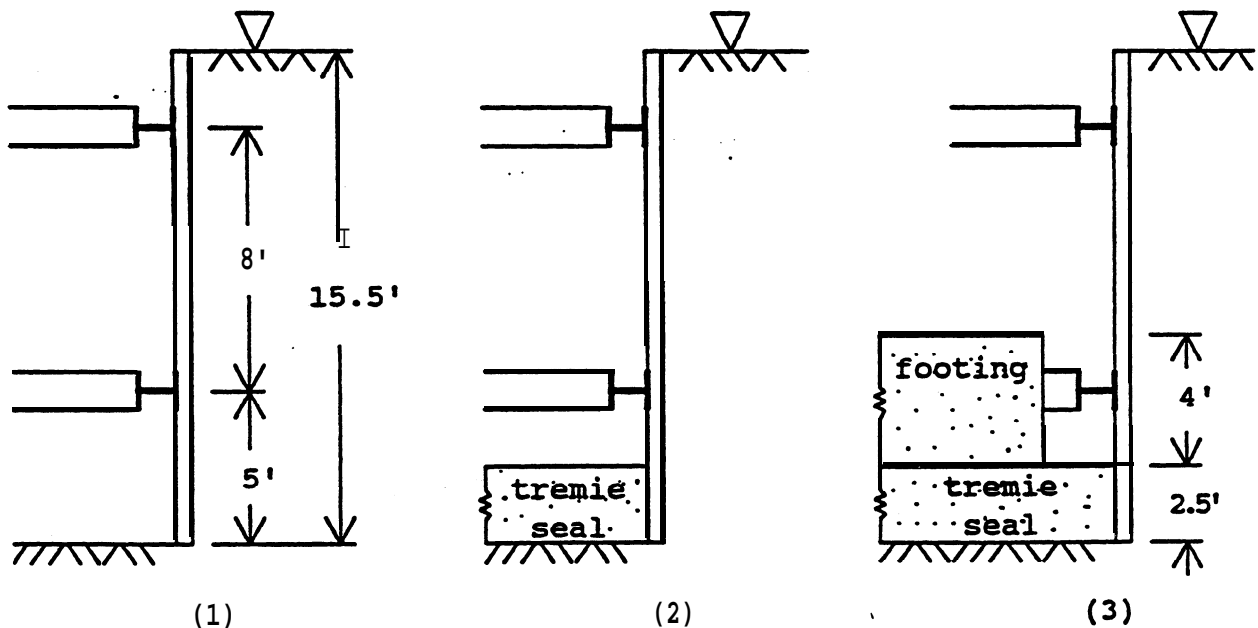
ELEVATION

SEQUENCE:
(1) Excavate and construct cofferdam, set cofferdam and backfill.
(2) Tremie, cure, dewater, and remove lower interior struts.
(3) Construct footing, cure, strut to footing, and remove top interior struts.

CASE (1):

Pressure Diagrams

P_A = (O.8)(Kw)(O.6)(15.5) = 260 psf
Minimum surchargeload = 72.0 psf
Water = (62.4) (15.5) = 967 psf

SOIL   WATER   COMBINED LOADING
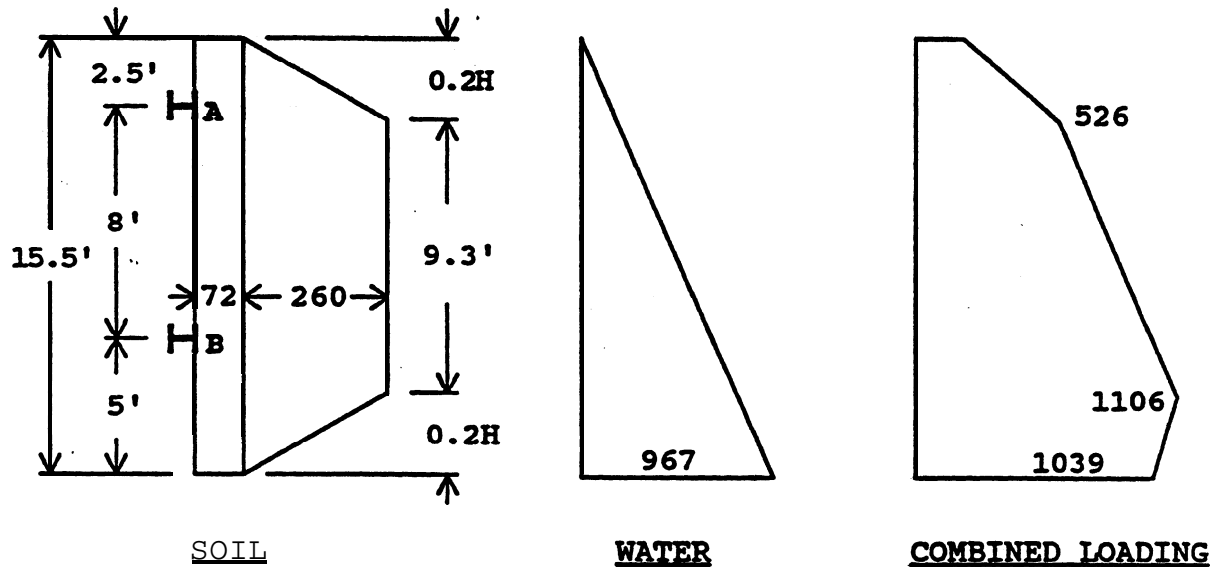
Check tremie vs. combined pressure (without surcharge load)

(2.5)(155) = 388 < 1,039 – 72 = 967 ∴ o.k.

Can the cofferdam be dewatered to permit construction of a footing lowered to the elevation of eliminated tremie seal? All struts to remain in place.

SHEETING

Five foot cantilever will be the most critically loaded location.
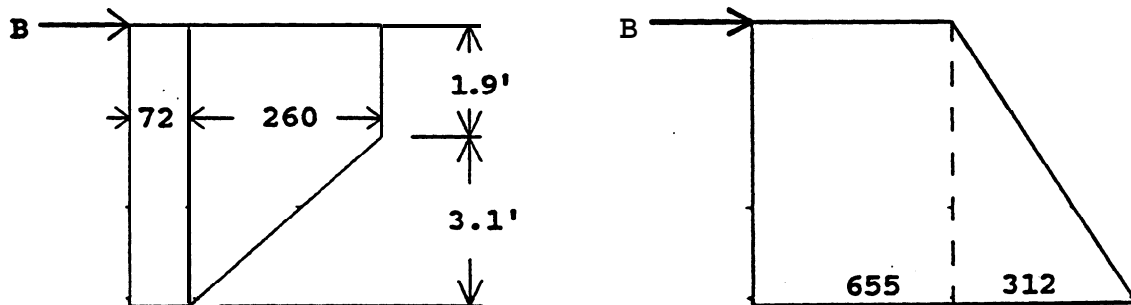
ΣM_B = (655) (5) [5/2] + (312) (5)[(5) (2/3)]/2 + (72) (5) [5/2]
        + (260) (1.9)[1.9/2] + (260) (3.1)[1.9 + (1/3) (3.1)]/2
      = 13,339 Ft-Lb/LF

For 16" wide timber M_B = (1.33) (13,339) Ft-Lb/Timber
Section Modulus Required = M/f (Use Load Duration Factor = 1.33)
S = (1.33)(13,339)(12)/(1,500)(1.33) = 106.7 in^3
S Furnished = (16)(4)^2/6 = 42.67 in^3

SHEETING WILL BE OVERSTRESSED IF COFFERDAM IS DEWATERED!

If sheeting had been sufficent at this point, the struts and walers
would have been checked next.

If not dewatered:
ΣM_B = (72)(5)[5/2] + (260)(1.9)[1.9/2]
        + (260)(3.1)[1.9 + (1/3)(3.1)]/2 = 2,551 Ft-Lb/LF
S required = (2,551/13,339)(106.7) = 20.4 < 42.67 in^3

CASE (2):

Place tremie concrete , dewater, and remove lower struts.

   Pressure Diagrams (above tremie concrete)
     P_A = (0.8)(3.5)(0.6)(13) = 218 psf
     Water = (62.4)(13) = 811 psf
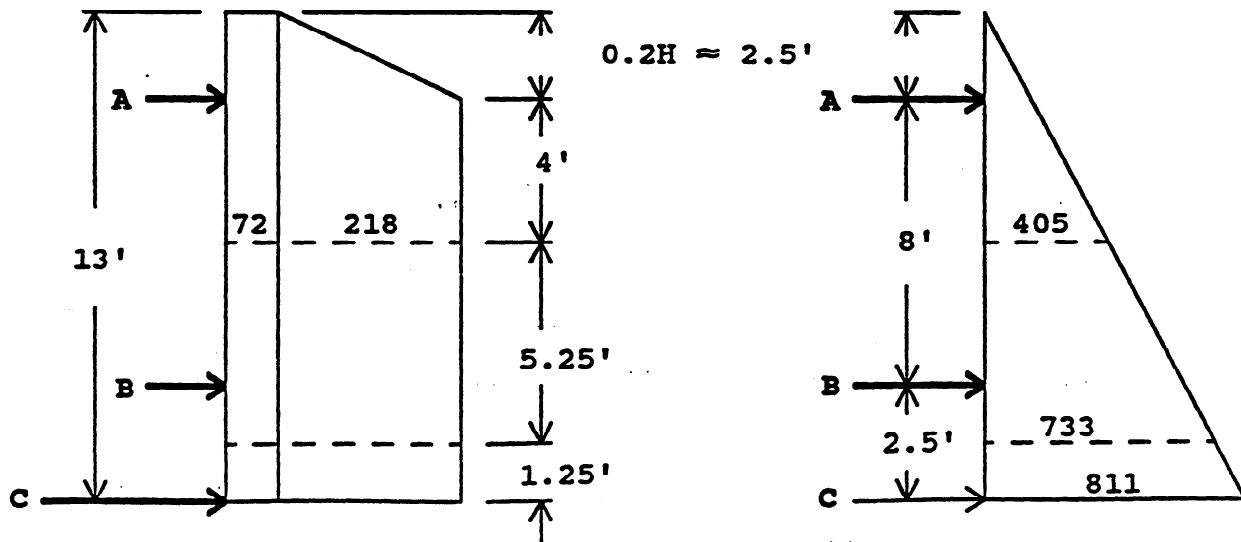
Determine reactions by approximate method of area division, then to
approximate moment distribution arbitrarily increase B by 10% and
prorate reaction difference to A and C.

REACTIONS

A = (218 + 72)(6.5) - (218)(2.5)/2 + (6.5)(406)/2
  = 2,932 Lb/LF
B = (218 + 72)(5.25) + (405 + 733)(5.25)/2
  = 4,510 Lb/LF
C = (218 + 72)(2.5)/2 + (733 + 811)(1.25)/2
  = 1,327 Lb/LF

Total Load = (218 + 72)(13) - (218)(2.5)/2 + (811)(13)/2
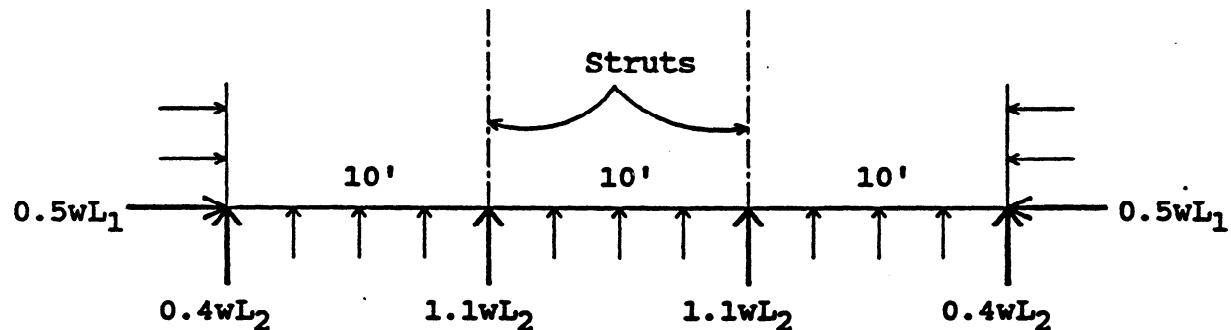   = 8,769 Lb/LF

Increase B by 10%: (4,510)(1.10) = 4,961 Lb/LF
Difference from previous value = 4,961 - 4,510 = 451
Prorate difference to A and C. 2,932/(2,932 + 1,327) = 0.69%

A = 2,932 - (0.69)(451) = 2,621 Lb/LF
C = 1,327 - (0.31)(451) = 1,187 Lb/LF

LOADING CONFIGURATION

LOWER STRUT

Properties of a W12 x 190: $I = 1,890$ in^4, $S = 263$ in^4,
$A = 55.9$ in^2, $r_x = 5.82$ in, $r_y = 3.25$ in

End load = (1.1)(4,961)(10) = 54,571 Lb
P/A = 54,571/55.9 = 976 psi
f_{all} = 16,000 - 0.38$(L/r)^2$ = 16,000 - 0.38$[(10)(12)/3.25]^2$
      = 15,482 psi

LOWER WALE

use (P/A)/f_{all} + (M/S)/FB $\leq$ 1.0
f_{all} = 16,000 - 0.38$[(10)[12]/5.82]^2$ = 15,838 psi

Check short side:

End load = (0.4) (4,961)(10) = 19,844 Lb
M = (4961)(10)^2/8 = 62,013 Ft-Lb = 744,156 in-Lb
(19,844/55.9)/15,838 + (744,156/263)/22,000 = O.15 < 1.0 ∴ o.k.

Check long side:

End load = (0.5) (4,961)(10) = 24,805 Lb
M = (4,961)(10)^2/10 = 49,610 Ft-Lb = 595,320 in-Lb
(24,805/55.9)/15,838 + (595,320/263)/22,000 = 0.13 < 1.0 ∴ o.k.

UPPER STRUT

Properties of a HP14 x 73: I = 734 in^4, S = 108 in^3,
A = 21.5 in^2, r_x = 5.85 in r_Y= 3.49 in

End load = (1.1)(10)(2,621) = 28,831 Lb
P/A = 28,831/21.5 = 1,341 psi
f_{all} = 16,000 - 0.38[(10)(12)/3.49]^2 = 15,551 psi

UPPER WALE

f_{all} = 16,000 - 0.381[(10)(12)/5.85]^2 = 15,840 psi

By inspection short side will be most critical:

End load = 0.4wL = (0.4)(2,621)(10) = 10,484 Lb
M = (2,621)(10)^2/8 = 32,763 Ft-Lb = 393,156 in-Lb
(10,484/21.5)/15,840 + (393,156/108)/22,000 = 0.20 < 1.0 ∴ o.k.

NOTE: Overstresses in steel members should not be allowed because:

  • Adequate soil data was not furnished.
  • Contractor may not be an expert in cofferdam construction
    (normally the case).
  • It is unlikely that the steel stresses will be frequently
    checked by means of strain gages.

REMOVE LOWER STRUTS

Moment will be based on proportion of load carried by wale.
Limit deflection of sheeting to L/240 and assume simple span of 10.5
feet.
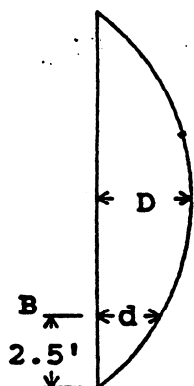
center Δ = L/240 = (10.5)(12)/240 = 0.5 in
d = (1-x/L) (4) (D) (x)/L)

   = (1-2.5/10.5)(4)(0.5)(2.5)/10.5
   = 0.36"

Load to be carried by 30' wale assuming simple
span for Δ = 0.36"

Δ = 0.36 = (5)(w)(30)^4(1,728)/[(384)(30x10^6) (1,890)]
$\therefore$w = 1,120 Lb/LF

M = (1,120)(30)^2/8 = 126,000 Ft-Lb = 1,512,000 in-Lb
(24,805/55.9)/15,838 + (1.5x10^6/263)/22,000 = 0.29 < 1.0 $\therefore$ o.k.

SHEETING

Disregard any reaction at B temporarily and solve for A and C reactions
(with sheeting assumed fixed at C) by approximate method of area
division.

A = (72)(2.5) + (290)(5.25) + (218)(2.5)/2 + (484)(7.75)/2
  = 3,851 Lb/LF
C = (290)(5.25) + [(484 + 811)/2]5.25
  = 4,922 Lb/LF

Make reaction at B = 1,120 Lb/LF and decrease A and C proportionally.

A = 3,851 - (2.5/10.5)1,120 = 3,584 Lb/LF
C = 4,922 - (8/10.5)1,120 = 4,069 Lb/LF

Maximum moment will either be at C or somewhere between A and B.
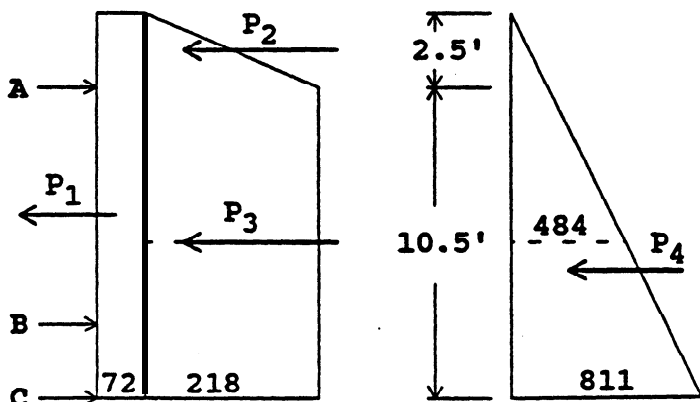
P$_1$ =   (72)(13)   =   936

P$_2$ = (218)(2.5)/2 =   273

P$_3$ = (218)(10.5) = 2,289

P$_4$ = (811)(13)/2 = 5,272
                     8,770

ΣM$_C$ = P$_1$(13/2) + P$_2$(10.5 + 2.5/3) + P$_3$(10.5/2) + P$_4$(13/3)
     - A(10.5) - B(2.5) = 3,609 Ft-Lb/LF

To find maximum moment between A and B find point of zero shear.

(62.4)(2.5) = 156
(62.4)(8) ≐ 499

499

655
↓
156

LOAD DIAGRAM

218
↓
72

A = 3,585   **B = 1,120**

2,937

648

X

1,511

2,631

SHEAR DIAGRAM
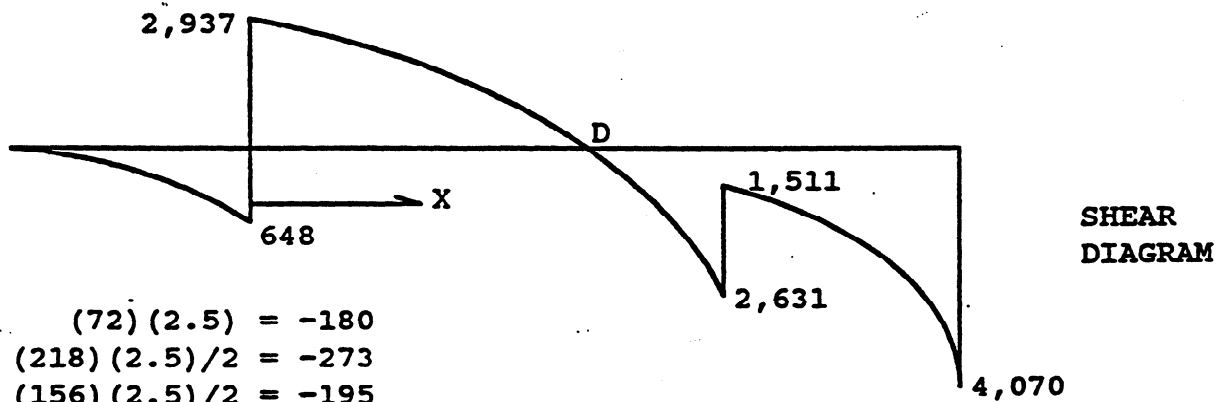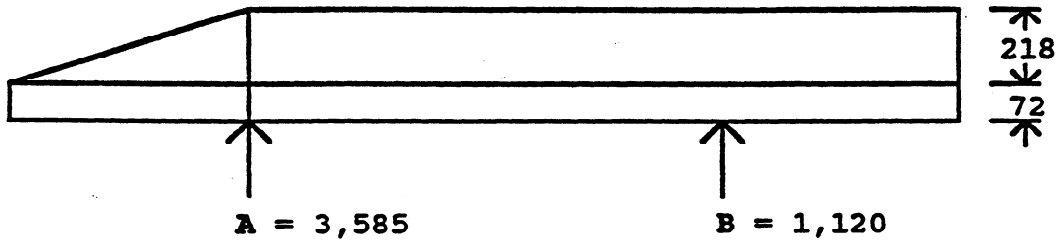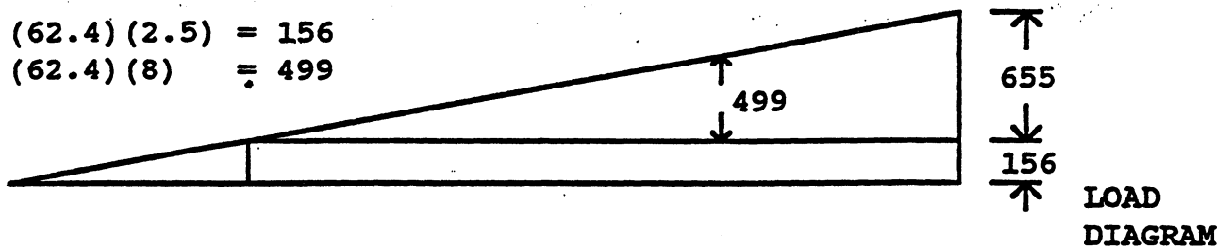
4,070

(72)(2.5) = −180
(218)(2.5)/2 = −273
(156)(2.5)/2 = −195
          −648

−648
3,585
2,937

          2,937
(290 + 156)8 = −3,571
(499)(8)/2 = −1,997
          −2,631

          −2,631
          1,120
          −1,511

                    −1,511
(290 + 156)(2.5) = −1,116
[(499 + 655)/2](2.5) = −1,443
                    −4,070

                    −4,070
                    4,076

$2937 - (290 + 156)X - (62.4)(X)^2/2 = 0$
$\therefore X = 4.9'$

$\Sigma M_D = (72)(7.4)[7.4/2] + (218)(2.5)[4.9 + 2.5/33/2$
$\qquad + (218)(4.9)[4.9/2] + (62.4)(7.4)^2[7.4/3]/2 - (3,584)[4.9]$
$\qquad = -7,197 \text{ Ft-Lb/LF} > 3,609 \therefore \text{ Controls}$

S required = $(16/12)(7,197)(12)/(1500)(1.33) = 57.6 > 42.67 \text{ in}^3$

LOWER STRUTS SHOULD NOT BE REMOVED !!

If the lower struts could have been removed, the wale load at the short ends would have increased from 0.4wL to 1.5wL and the struts would be rechecked for structural adequacy.

CASE (3):

Can the top struts be removed if the lower struts remain in place?

Pressure diagrams will be the same as for CASE(2). Initial reactions are A = 2,621, B = 4,961, and C = 1,187 Lb/LF. Without the top struts, the upper wales and sheeting will deflect inward increasing the reaction at B and decreasing the reaction at C.

Deflection of the sheeting and upper wale at A must be the same. Determine the load that can be carried by the upper wale. Limiting load to be determined by the combinationof axial and bending stress, or by the load which limits deflection to L/240. Determine deflection for limiting load. Determine the maximum load the sheeting will take to have the same deflection as the wale at the location of the A reaction. If the sum of the wale and sheeting limiting loads are less than the reaction of A (2,621 Lb/LF), the wale or the sheeting will be overloaded and/or overstressed. Assume the sheeting to be a cantilever fixed at B.

UPPER WALE

Determine allowable load for 30' span

End load = 0.5wL = (0.5)(2,621)(10) = 13,105 Lb
$M = w(30)^2/8 = 112.5w \text{ Ft-Lb} = 1350w \text{ in-Lb}$

$f_{all} = 15,840 \text{ psi}$

$(13,105/21.5)/15,840 + (1350w/108)/22,000 = 1.0$
$\therefore$ limiting wale load w = 1,692 Lb/LF

Determine maximum deflection.

Limiting load deflection A = $5wL^4/384EI$
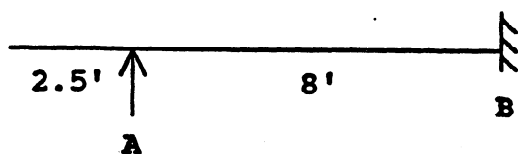= $(5)(1,692)(30)^4(12)^3/(384)(30\times10^6)(734)$ = 1.4"

$\Delta \leq L/240$ = $(30)(12)/240$ = 1.5"
∴Limiting load on wale is governed by stresses rather than deflection.

SHEETING

Limit sheeting at reaction A to wale deflection of 1.4"

Δ at A = $[(w)(b)^3(12)^3/3EI)$
where b = 8'

$I = (16)(4)^3/12 = 83.33$ in^4
= 64 in^4/LF

1.4 = $[(w)(8)^3(12)^3/(3)(1.6\times10^6)(64)$
∴w = 486 Lb/LF

1,692 + 486 = 2,178 < 2,623

WALE WILL BE OVERLOADED - DO NOT REMOVE TOP STRUTS !!

Not checked:
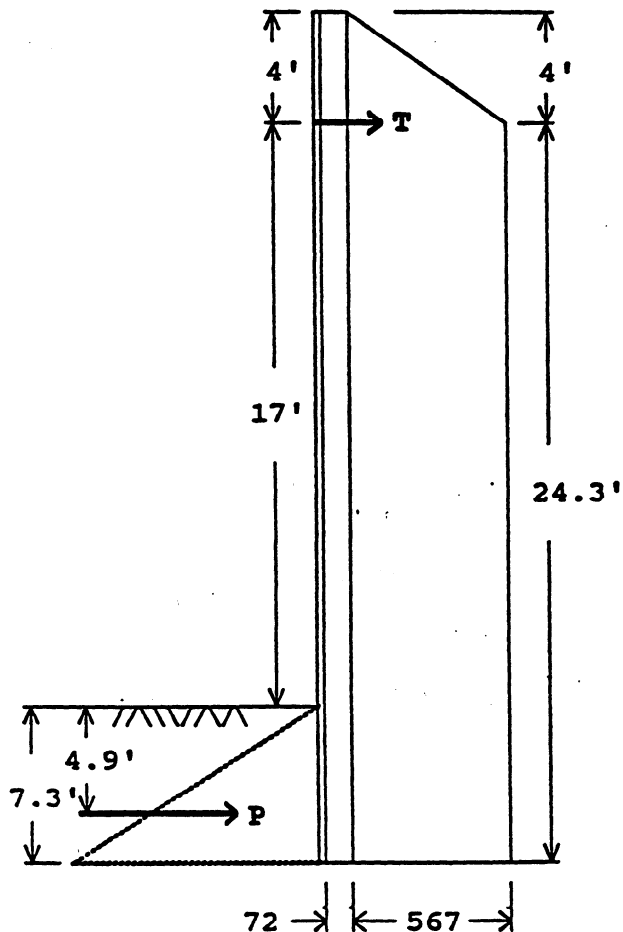
Wale web crippling
Welding
Sheeting to wale connections
Buoyancy

SAMPLE PROBLEM NO. 28 - DEFLECTION

Horizontal movement, or deflection, of shoring systems can only be roughly approximated because soils do not apply pressures as a true equivalent fluid, even in the totally active state. A deflection calculation can be made by structural mechanics procedures (moment area - M/EI) and then some soundengineering judgment should be used. In general, cohesionless soils will give about 1/2 the calculated values, & cohesive even less. The time that the shoring is in place will also affect movement. Monitoring, or performance testing, is the final answer.

Following is an example of a deflection calculation for a sheet pile with a single tieback. It is assumed that the lock-off load of the tie is sufficient to preclude any movement at the tie support. The moment-area method will be used to calculate deflections.

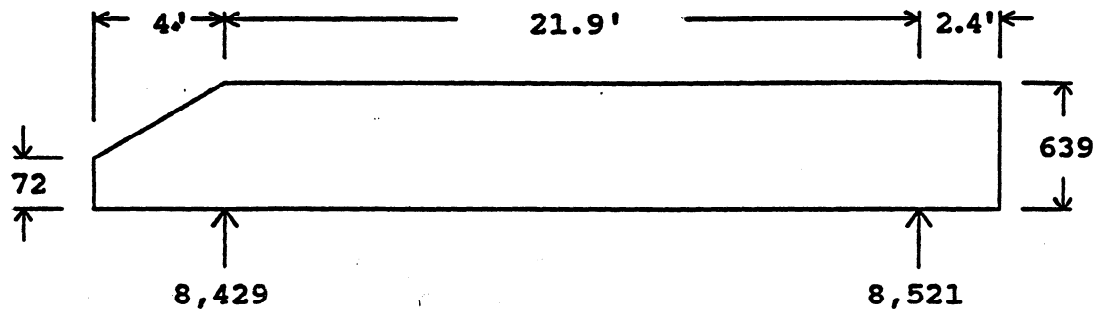P = the total passive reaction
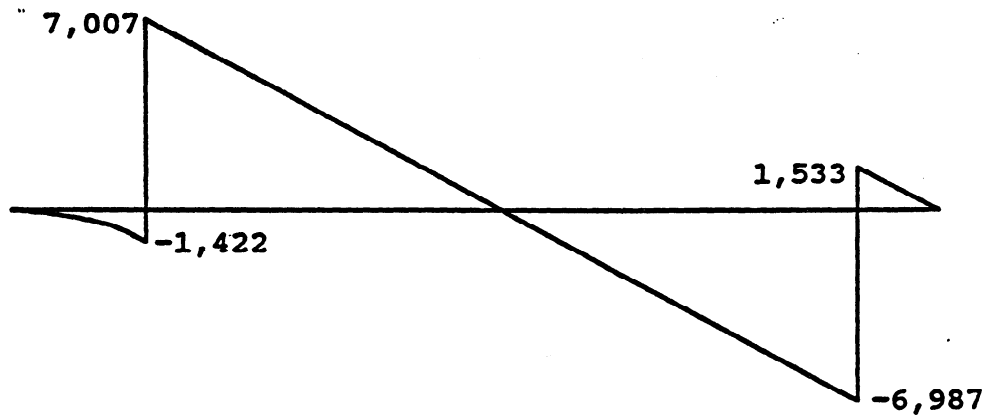 = 8,521 Lb/LF

T = 8,429 Lb/LF

E = 30 x 10^6 psi

I = 109 in^4

LOAD DIAGRAM

4.' 21.9' 2.4'

639

72

8,429 8,521

SHEER DIAGRAM

7,007

1,533

−1,422

−6,987

MOMENT DIAGRAM

36,330

32,493 32,339

20,828 20,520

−2,088 A −1,840

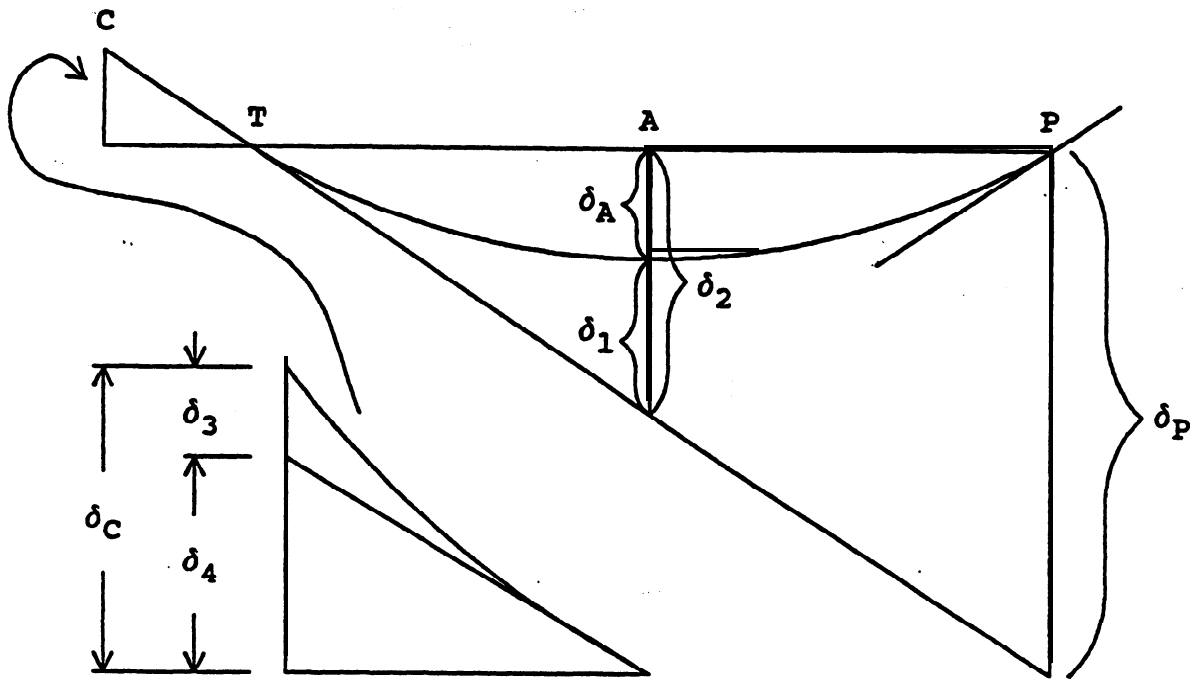4.0' 4.0'

0.3' 3.7' 3.5' 3.5' 3.5' 3.5' 3.6' 0.3'

T 21.9' P
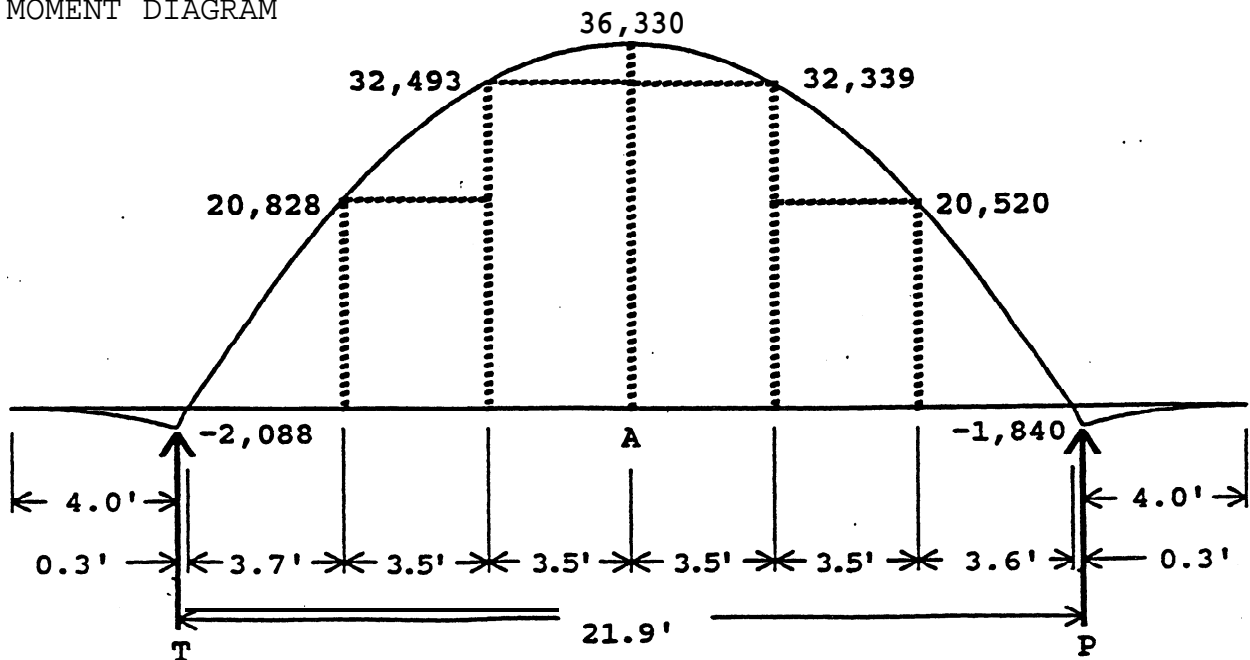
Determine the deflection δ_P

$\delta_2 = (\delta_P)(11.0/21.9)$

Determine the deflection of the tangent to the elastic curve at the centerline from the tangent at T (δ_1).

The true deflection at A $= \delta_2 - \delta_1 = \delta_A$

$\delta_P = ((-2,088)(0.3/3)[21.6 + (3/4)(0.3)]$
$+ (36,330)(10.7)(2/3)[10.9 + (3/8)(10.7)]$
$+ (36,330)(10.6)(2/3)[0.3 + (5/8)(10.6)]$
$- (1,840)(0.3/3)[0.3/4])(1,728)/(30 \times 10^6)(109)$
$= 2.98$ in

$\delta_2 = (2.98)(11.0/21.9)$
$= 1.50$ in

$\delta_1 = (-2,088)(0.3/3)[10.7 + (3/4)(0.3)]$
$+ (36,330)(10.7)(2/3)[(3/8)(10.7)](1,728)/(30 \times 10^6)(109)$
$= 0.55$ in

$\delta_A = 1.50 - 0.55$
$= 0.95$ in

The deflection at the cantilever section will be the sum of the difference between the tangents to the elastic curves at point T and **C: (δ_3)** and δ_4.

δ_3 = ((-2,088)(4.0)/4)[(4,5)(4)](1,728)/(30 x 10^6)(109)
   = -0.004 in

By similar triangles, δ_4 = (2.98)(4.0/21.9) = 0.544 in

$\delta_{\overline{C}}$ δ_3 + δ_4 = -0.004 + 0.544 - 0.54 in